

**METHOD AND APPARATUS FOR PROCESSING MULTIPLE COMMON
FREQUENCY SIGNALS THROUGH A SINGLE CABLE**

[0001] RELATED APPLICATIONS

[0002] The present application claims priority from US Provisional Application 60/458,012 filed March 28, 2003 and is related to co-pending US Patent Application Serial Number _____ filed on August __, 2003 in the name of Deane et al. and titled "METHOD AND APPARATUS FOR PROCESSING MULTIPLE COMMON FREQUENCY SIGNALS THROUGH A SINGLE CABLE USING CIRCULATORS"

[0003] BACKGROUND OF THE INVENTION

[0004] Field of the Invention

[0005] The present invention relates to the field of radio frequency (RF) transmission and signal processing related thereto. More specifically, the present invention pertains to a method and apparatus for processing multiple signals at a common frequency fed through a single RF cable with or without one or more amplifiers and utilized for either forward or reverse link transmissions.

[0006] DESCRIPTION OF THE PRIOR ART

[0007] In the area of RF transmission, many problems exist with regard to cost and reliability of components. This is particularly true when considering typical antenna structures and RF circuitry elements related to such antenna structures. Most antenna structures are inherently inhospitable environments due to their exposure to wind, precipitation, and temperature extremes. Such environmental difficulties often cause premature failure of RF circuitry elements located on antennas, thus necessitating truck rolls and costly technician time. Further, some RF circuitry elements are considered more vulnerable to failure. Still further, placement of RF circuitry elements at or near the antenna masthead presents logistical, if not safety, concerns due to the difficulty of

physical access. In instances where removal of the masthead for subsequent repair is the only manner of access, significant system downtime will occur. Accordingly, designers of RF systems are always looking for ways to reduce placement of high power (and relatively low reliability) RF circuitry elements at the antenna and masthead.

- [0008] In addition to physical considerations, designers of RF systems must also contend with maintaining systems losses at a minimum.

- [0009] Antenna structures within many RF transmission systems that are multi-sectored such as, but not limited to, code division multiple access (CDMA) systems typically include technologies that require a high power amplifier (HPA) for each sector. For purposes of this application, it should be understood that where the term “antenna structure” is used it should be read to include any antenna itself or may also include a tower, building, or similar physical means that supports the given antenna.

- [0010] Due to the low reliability of the HPA elements, HPAs are normally placed at the base of the antenna structure. As each signal is run through a given HPA, this aspect necessitates multiple runs of RF cabling to antenna ports on the antenna masthead. Often, such multi-sectored systems will also include features such as beam-splitting and directional antenna arrays that further crowd the antenna tower itself with requisite RF cabling. Aside from weight considerations, wind load becomes an increasing concern with the increase of RF cabling. In instances of environmental occurrences such as ice build-up and/or high winds, an abundance of surface area in the form of RF cabling can result in catastrophic failure of the antenna structure.

- [0011] What is needed therefore is a manner in which costly, high power (but low reliability) RF circuitry elements are eliminated in regards to the antenna-related portion (i.e., masthead) of an RF system such as, but not limited to, a CDMA system. Further, what is needed is a manner in which multiple runs of RF cabling are reduced.

[0012] SUMMARY OF THE INVENTION

[0013] The present invention provides a method and apparatus for processing multiple signals occupying a common frequency through a single RF cable. The inventive method and apparatus may include one or more HPAs located at the base of the antenna structure for forward link transmission. In the case of reverse link transmissions, the method and apparatus of the present invention would not require HPAs at the base of the antenna structure, but would rather require preamplifiers located at the masthead of the antenna structure. It should be understood that such preamplifiers would be relatively low power and therefore of a suitable reliability for placement at the masthead without compromising the value of the present invention.

[0014] In the instance where multiple HPAs are used at the base of the antenna structure with distinct signals (at a common frequency), the HPAs would be located prior to combining the signals and feeding them into a single RF cable. In the alternative instance where a single HPA is used, the single HPA would be located after combining the signals but prior to feeding the combined signals into a single RF cable. Either of these two instances are most suitable for forward link transmission and it should be readily understood that the specific location and placement of one or more HPAs may vary due to the given implementation of the present invention without straying from the intended scope of the instant method and apparatus. Moreover, the existence of even one HPA is not necessitated by the present invention. Rather, the method and apparatus of the present invention is suitable for reverse link transmission where no HPAs are used. In such instance, relatively reliable, low power preamplifiers would be located at the antenna masthead of the antenna structure.

[0015] The present invention is operable for forward link transmission by way of combining multiple signals (before or after amplification by one or more HPAs as mentioned above) at the base of an antenna structure, transmitting the combined signal through a single RF cable to the antenna masthead, and de-combining the combined signal prior

to transmission of the multiple signals to a set of antenna ports for signal propagation therefrom.

[0016] The present invention is operable for reverse link transmission by way of combining multiple signals after pre-amplification using low power amplifiers at the masthead of an antenna structure, transmitting the combined signal through a single RF cable to the base of the antenna structure, and de-combining the combined signal prior to transmission of the multiple signals to a set of input ports (e.g., base-station receiver inputs) for signal transmission therefrom.

[0017] The inventive aspect of combining multiple signals within the same frequency and subsequently de-combining such aggregate signal reduces costly high power RF circuitry elements in regards to the antenna-related portion of an RF system such as, but not limited to, a CDMA system with a masthead HPA and RF cabling. Indeed, the present invention is system-independent (i.e., independent of modulation format) in that any RF system transmitting multiple signals at a common frequency over a single RF cable would benefit from the inventive method and apparatus disclosed herein.

[0018] The method and apparatus of the present invention is accomplished by way of a modulation/demodulation scheme using Walsh codes and modified Wilkinson combiner. The Walsh code modulation/demodulation scheme is discussed further hereinbelow. The basic concept within the present invention is the same for either the forward or reverse links. That is to say, forward and reverse link transmissions occurring within the scope of the present invention both include the advantageous aspects of modulating signals having a common frequency, combining such signals so as to pass the combined signal along a single RF cable, and de-combining and de-modulating the combined signal in order to reconstitute the original signals without significant losses, distortion, or cross-talk.

[0019] In the instance of forward link transmission, multiple (N) signals having a common frequency are each modulated by a short Walsh code phase sequence by way of a

respective phase shifter at each of N inputs. Specifically, the multiple signals are phase shifted according to a short Walsh modulation sequence (of length 4 chips in the illustrated example). The phase-shifted signals are then combined to form an aggregate signal. The aggregate signal is then amplified by way of passing through a single HPA. Alternatively, as mentioned above, these signals may be amplified prior to being modulated by the Walsh code sequences and subsequently combined. This allows the amplified aggregate signal to pass through a single RF cable up the length of an antenna structure. At the antenna masthead, the amplified aggregate signal is split via a delay line together with a modified Wilkinson combiner and then demodulated via the Walsh demodulation scheme. Each related demodulated, phase-shifted signal then passes to a predetermined related antenna port for propagation therefrom.

[0020] In the instance of reverse link transmission, multiple (N) signals having a common frequency are received at respective antenna ports and then amplified by way of passing through a respective low power preamplifier located at the antenna masthead. Each amplified signal is then modulated by a short Walsh code phase sequence by way of a respective phase shifter. Specifically, the multiple signals are phase shifted according to a short Walsh modulation sequence (of length 4 chips in the illustrated example). The phase-shifted signals are then combined to form an aggregate signal. This allows the amplified aggregate signal to pass through a single RF cable down the length of an antenna structure. At the base of the antenna structure, the amplified aggregate signal is split via a delay line together with a modified Wilkinson combiner and then demodulated via the Walsh demodulation scheme. Each related demodulated, phase-shifted signal then passes to a set of input ports (e.g., base-station receiver inputs) for signal reception.

[0021] While the present invention may be utilized in a manner whereby the method and apparatus may be arranged in order to provide for either signal receiving or transmission as outlined above, for purposes of clarity the example discussed in more detail below will primarily focus on the forward link. It should be well understood

that one of ordinary skill in the art of digital signal processing would recognize the reverse link variation to be well within the intended scope of the present invention. As well, one skilled in the art would recognize that a detailed implementation would require circuitry details that are only discussed in general terms below. Again, any such generalities are for the purposes of clarity of illustrating a preferred embodiment of the present invention.

[0022] **BRIEF DESCRIPTION OF THE DRAWINGS**

[0023] **FIGURE 1** is a block diagram illustrating two common carrier signals combined and recovered in accordance with the present invention.

[0024] **FIGURE 1A** is a block diagram illustrating a different input portion of the diagram shown in **FIGURE 1** including multiple amplifiers for a forward link configuration of the present invention.

[0025] **FIGURE 1B** is a block diagram illustrating another different input portion of the diagram shown in **FIGURE 1** including a single amplifier for a forward link configuration of the present invention.

[0026] **FIGURE 1C** is a block diagram illustrating a different output portion of the diagram shown in **FIGURE 1** including multiple amplifiers for a reverse link configuration of the present invention.

[0027] **FIGURE 2** is a flowchart overlaying a block diagram illustrating the signal processing occurring at the various stages of **FIGURE 1**.

[0028] **FIGURE 3** is a block diagram illustrating three common carrier signals combined and recovered in accordance with the present invention.

[0029] DETAILED DESCRIPTION OF THE INVENTION

[0030] The invention will be described for the purposes of illustration only in connection with certain embodiments; however, it is to be understood that other objects and advantages of the present invention will be made apparent by the following description of the drawings according to the present invention. While a preferred embodiment is disclosed, this is not intended to be limiting. Rather, the general principles set forth herein are considered to be merely illustrative of the scope of the present invention and it is to be further understood that numerous changes may be made without straying from the scope of the present invention.

[0031] During operation of a CDMA system or any related RF system, one sector corresponding to a multi-sector antenna may reach peak traffic capacity and generally require full power. Conventionally, in a three sector cell for example when three cables are run up an antenna tower and three corresponding HPAs exist to send each signal up the corresponding cable, there is no way that power can be transferred between sectors should one sector require more than the other two. In the present invention, power is effectively shared among the three sectors because the signals are combined and full power is effectively always available for any sector. This is accomplished via the trunking aspect of one HPA and one cable.

[0032] With reference to **FIGURE 1** there is illustrated an example of a first embodiment **100** of the present invention using modulation/demodulation implemented via Walsh codes. While only two signal input channels **10, 11** for corresponding sectors are shown, it should be understood that any number of sectors and corresponding signals (i.e., N number of signals) are possible with the current invention. The two channels **10, 11** (e.g., CDMA forward link sectors or beams) are modulated via fast chip Walsh modulators **12, 13** as shown.

[0033] Generally speaking, Walsh modulation/demodulation involves the use of Walsh codes to distinguish different signals during transmission. It will be appreciated by those

skilled in the art that several different spreading codes exist which can be used to separate data signals from one another in a CDMA communication system. These spreading codes include but are not limited to pseudo noise (PN) codes and Walsh codes. A Walsh code corresponds to a single row or column of the Hadamard matrix. For example, in a 64 channel CDMA spread spectrum system, particular mutually orthogonal Walsh codes can be selected from the set of 64 Walsh codes within a 64 by 64 Hadamard matrix. Also, a particular data signal can be separated from the other data signals by using a particular Walsh code to spread the particular data signal.

[0034] Further, it will be appreciated by those skilled in the art that spreading codes can be used to channel code data signals. The data signals are channel coded to improve performance of the communication system by enabling transmitted signals to better withstand the effects of various channel impairments, such as noise, fading, and jamming. Walsh codes can be used to channel code a data signal prior to modulation of the data signal for subsequent transmission. Other orthogonal or quasi-orthogonal methodology may also be used for modulation within the inventive method and apparatus for an equivalent implementation without straying from the intended scope of the present invention. In order to use Walsh codes in signal spreading or channel coding, the Walsh codes must be readily available for use. One technique for making the Walsh codes readily available is to generate the Walsh codes by placing the desired Walsh codes in a memory-based lookup table. Subsequently, as each Walsh code is needed, it must be retrieved from the lookup table.

[0035] In the present invention, the modulation used is a four chips long Walsh code – e.g., a 4x4 Walsh code matrix. With continued reference to **FIGURE 1**, each of the two input channels **10, 11** is bi-phase shift key (BPSK) modulated by a unique (and different) Walsh code (within modulators **12, 13**) from the four available. The modulation rate is synchronized to the normal CDMA chip rate but is at N times this rate (i.e., 4 Fc). The effect of this (fast) Walsh code modulation on the normal CDMA chips is to produce a $\text{Sin}(x)/x$ spectrum with sidebands separated by $N \cdot F_c$ centered at the carrier frequency. Consider the input channel **10** is modulated with the fast Walsh

code zero (0). The signal component for input channel **10** will enter the “in-phase” splitter **16** and be differentially delayed by $\frac{1}{2}$ slow chip (i.e., two “fast” chips delay line **17**).

[0036] With continued reference to **FIGURE 1**, Walsh code modulated signals are then combined into one RF stream by a combiner **14**. If forward link transmission occurs, then the input signals **10**, **11** may each be amplified prior to modulation by way of a corresponding high power amplifier (HPA) **30**, **31** as shown in **FIGURE 1A**. Alternatively, a common HPA **32** placed after the combiner **14** as shown in **FIGURE 1B** is also possible for the forward link implementation of the present invention. It is important to note that such combining allows a single RF cable **15** to be used between the one or more HPAs and the demodulation elements **12a**, **13a** located at the masthead (not illustrated). While a slightly larger cable is needed, windage and related structural upgrades to the antenna tower are significantly reduced by the use of only one cable **15**. Initial experimental results indicate in regard to the present invention that the power losses in a single cable, depending upon the length of cable required can minimize or possibly outweigh the losses in increased demodulation.

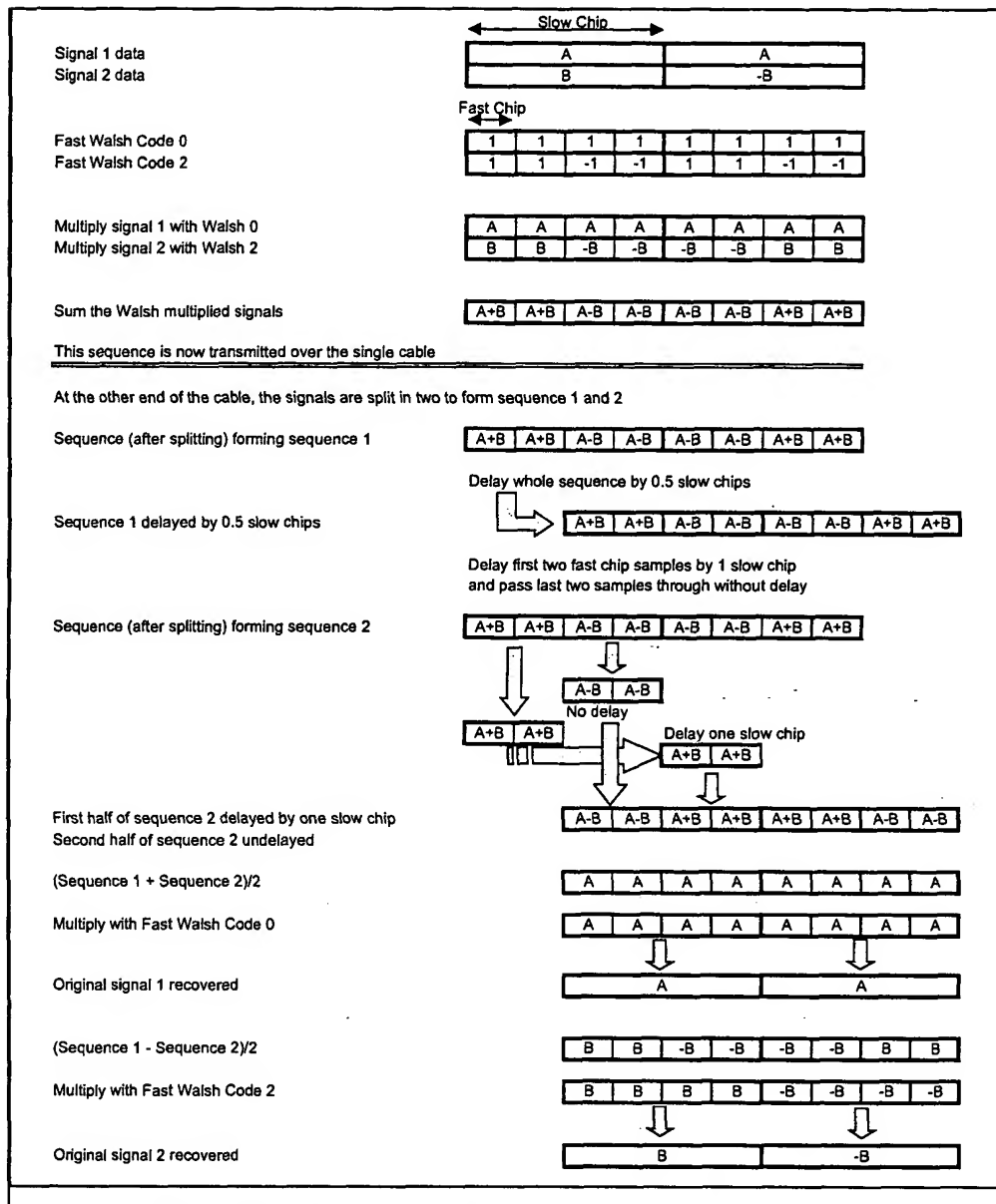
[0037] Next, the two differential signals are applied to the hybrid that splits the aggregate signal into two different paths. The combination of the two “fast” chips delay line **17** and the four “fast” chips delay line **18** (together with the associated switching circuitry **19**, **20**) functions like a “comb filter” which forces the differential RF signals from Walsh codes 0 and 1 to appear at the “in-phase” port of the Modified Wilkinson combiner **22**, while those from Walsh codes 2 & 3 appear at the “anti-phase” port of the same combiner **22**. Consequently, the combination of a switched delay line filter (collectively elements **16**, **17**, **18**, **19**, **20**, and **21**) and modified Wilkinson combiner **22** acts as a demux **300** in the form of a high power RF Walsh code discriminator.

[0038] The modified Wilkinson combiner **22** is configured as a 4-port, relative-phase discriminator. This means that signals appearing at the two input ports (port 1 & port 2) that are “in phase” are combined at the sum output (port 3), whereas signals that

appear at the input ports that are in “anti-phase” appear at the difference port (port 4). The primary modification to the standard Wilkinson combiner is that the balance resistor normally used to dissipate anti-phase signal energy is replaced with an RF transformer that provides a low loss path to the difference port (port 4). However, any (low loss) circuit that can effectively discriminate between two input signals that are “in phase” or in “anti-phase” could be used in place of the Wilkinson combiner 22 for purposes of the present invention.

[0039] The final stage of the process occurs when the signals are re-constituted by the de-modulators 12a, 13a that are effectively identical in operation to the modulators 12, 13. Filters 23, 24 further assure reconstituted output signals 10a, 11a are substantially identical to input signals 10, 11 and free of any distortion. It should be readily understood that transmission may also be in the reverse link without straying from the intended scope of the present invention in addition to the forward link mentioned in regard to **FIGURES 1A** and **1B** above. In such instance of reverse link transmission under the present invention, no HPAs would be used. Rather, low power preamplifiers 33, 34 as shown in **FIGURE 1C** would be required.

[0040] In the illustrated embodiment of **FIGURE 1**, the modulators 12, 13 and de-modulators 12a, 13a include $\lambda/2$ lines switched in or out by PIN diode switches controlled by clock signals derived from the transceiver's $N \cdot F_c$ clocks. While PIN diodes are described herein, it should be readily understood by those skilled in the art that any suitable switching element may be used. **TABLE 1** below indicates the signal processing occurring within **FIGURE 1**.

[0041] **TABLE 1**

[0042] **FIGURE 2** shows graphically a series of signal simulations. Each graphical representation shown corresponds to a specific stage of the signal processing of **FIGURE 1**. From **FIGURE 2**, input signals 10, 11 are represented by corresponding graphs 80, 81. After modulation 12, 13 and combining 14, the aggregate signal is shown in graph 82 with signal 1 components and signal 2 components corresponding to input signal 10 and 11, respectively. The aggregate signal is transmitted through a

length of RF cabling 15. Demultiplexing occurs at the other end of the RF cabling 15 and is represented by the demux 300 shown and results in graphs 83 and 84 corresponding to each modulated signal 1 and signal 2 components. Each demuxed, modulated signal is then demodulated by a corresponding demodulator 12a, 13a to form recovered signals 10a, 11a as shown in graphs 85 and 86.

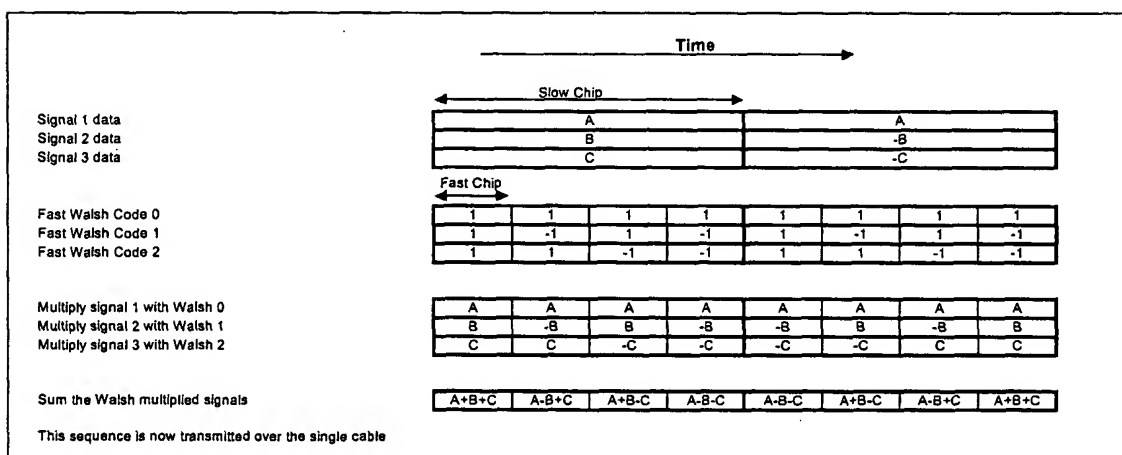
- [0043] The demux 300 shown in FIGURES 1 and 2 represents a splitter 16, delay line 17, 18, 19, 20, 21, and a modified Wilkinson combiner 22. Operationally, the demux 300 discriminates between signals (i.e., sectors) that have been pre-coded with different Walsh codes by way of a relatively narrow band filter constructed with a delay line 17, 18, 19, 20, 21, together with a modified Wilkinson combiner 22. Such filter performs its discrimination task because Walsh codes express their mutual orthogonality in the frequency domain. Specifically, for a four chip Walsh code set to combine two sectors, there are four frequencies separated by $F_c/4$ that can be combined to produce each and every one of the four Walsh code ship sets. For example, the first Walsh code (i.e., Walsh code zero) has a zero offset frequency from the input signal. That is to say, the original signal is unaltered after modulation with Walsh code zero. Consequently, the only spectrum of Walsh code-zero is only occupied at offset frequency zero. This spectrum is contrasted with that of Walsh code 2 which has its energy at offset frequencies of $1 \cdot F_c/4$ and $3 \cdot F_c/4$.
- [0044] Ideally, a high power, low loss filter with small component count that discriminated between odd and even offset frequencies (i.e., zero and $2 \cdot F_c/4$ or 1 and $3 \cdot F_c/4$ in this instance) would discriminate between Walsh code zero and Walsh code 2. According to the present invention, a simple delay line filter (collectively 17, 18, 19, 20, 21 in FIGURE 1) performs this odd/even frequency discrimination where $F(t)/2 + F(t + 2 \text{ chips})/2$ only passes the Walsh codes zero and 1 (from the set of four), whereas $F(t)/2 - F(t + 2 \text{ chips})/2$ only passes the Walsh codes 2 and 3 from the set. Accordingly, connecting the delayed and un-delayed chips to the two combiner inputs of the modified Wilkinson combiner causes the even offset frequencies (Walsh codes zero and 1) to appear at the normal (even mode) output and the odd offset frequencies

(Walsh codes 2 and 3) to appear across the fourth (odd mode) Wilkinson port. The fourth Wilkinson port typically has a 100 ohm resistor, but is modified according to the present invention to include a 50 ohm resistor. It should be noted that it is also possible to use a 4 port, 90 degree hybrid for this purpose so long as low RF losses of less than 0.2 dB exist.

[0045] As mentioned above, the present invention may be used for any number of signals. Although only two signals have been thus described with regard to the present invention, **FIGURE 5** shows an example of the underlying inventive concepts applied to a three-sector arrangement.

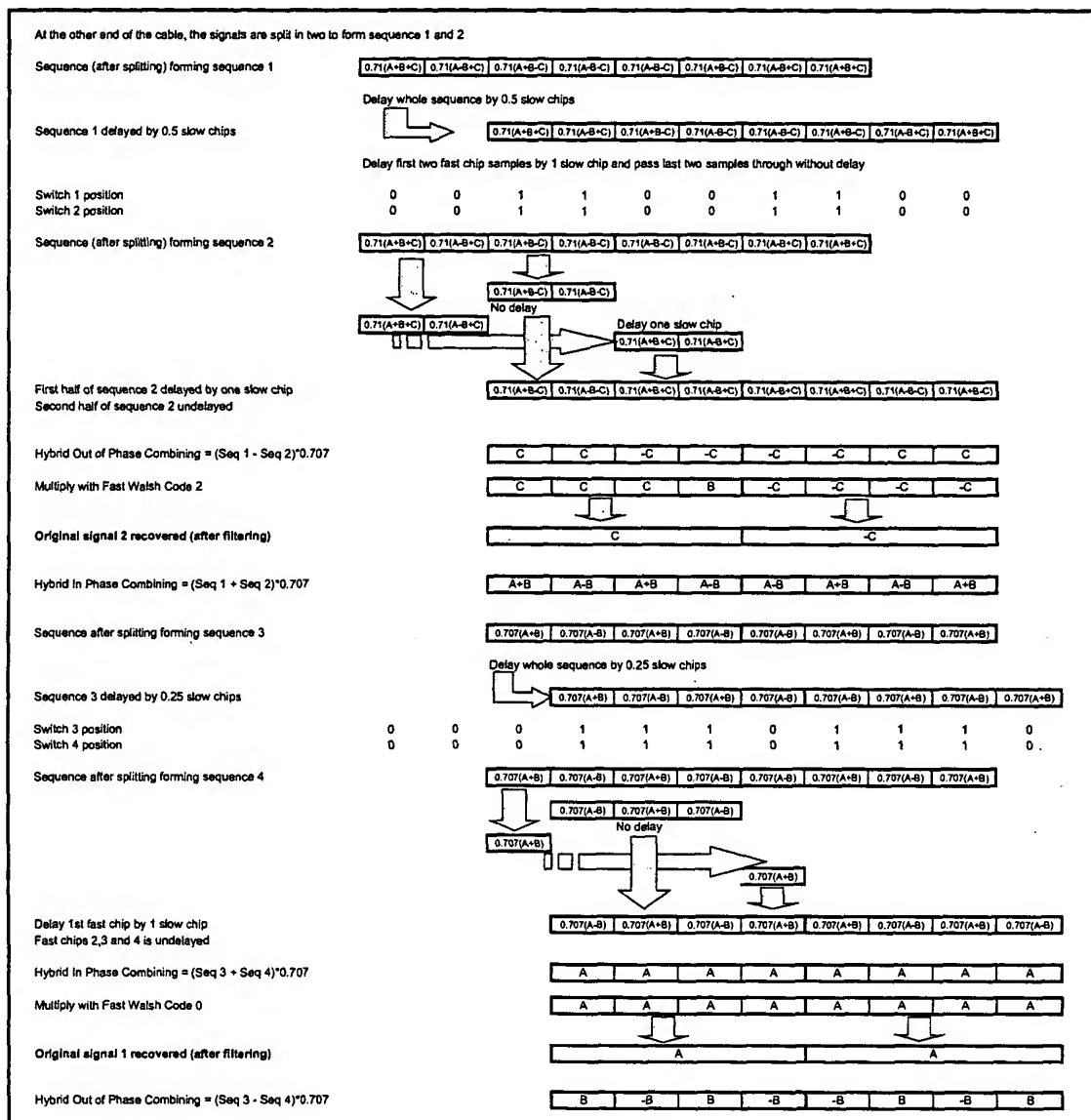
[0046] **FIGURE 5** shows a block diagram processing three (3) input signals **40, 41, 42** in accordance with the present invention. Each input signal **40, 41, 42** is modulated via modulators **43, 44, 45** as described above with regard to **FIGURE 1**. The modulated signals are then combined by combiner **46** and passed through a length of RF cabling **47**. Though not shown, multiple HPAs or a single HPA may be provided in a manner as described above during forward link transmission. After transmission through the RF cabling **46**, the aggregate signal stream passes through first splitter **50** and passes through a first and second demux (collectively **50-56** and **60-66**, respectively) that are arranged in a cascaded manner. **TABLE 2** below shows the signal processing up to the length of RF cabling **47**.

[0047] TABLE 2



- [0048] More specifically, the aggregate signal stream passes through a first delay line (collectively **51, 52, 53, 54, 55**) and subsequently a first modified Wilkinson combiner **56** in a manner as described with respect to **FIGURE 1**. However, in this three sector configuration, the difference port of the first combiner **56** passes a signal component corresponding to input signal **42** to demodulator **45a** and filter **72** to output a reconstituted signal **42a** that corresponds substantially identically to input signal **42**. The sum port of the first combiner **56** passes the remaining signal component corresponding to input signals **40, 42** into the second demux (collectively **60-66**). That remaining signal component is split by a second splitter **60** and processed by a second delay line (collectively **61, 62, 63, 64, 65**) and subsequently a second modified Wilkinson combiner **66** again in a manner as described with respect to **FIGURE 1**.
- [0049] At this point, the difference port of the first combiner **56** passes a signal component corresponding to input signal **40** to demodulator **43a** and filter **70** to output a reconstituted signal **40a** that corresponds substantially identically to input signal **40**. The sum port of the second combiner **66** passes the remaining signal component corresponding to input signal **41** to demodulator **44a** and filter **71** to output a reconstituted signal **41a** that corresponds substantially identically to input signal **41**. **TABLE 3** below indicates the signal processing occurring within **FIGURE 3** after the length of RF cabling **47**.

[0050] TABLE 3



[0051] It should be readily understood that reducing the conventional manner of using multiple HPAs and cables by way of the present invention reduces system costs in that the HPA is one of the costliest elements of the basestation. However, it should also be noted that multiple HPAs may still benefit by the demodulation configurations as outlined by the present invention.

- [0052] Further, it is within the intended scope of the present invention that even if multiple HPAs are used, the total number of HPAs can be reduced as the N:1 relationship of input signals to aggregate signals may occur anywhere in the system. Accordingly, a CDMA communications system and the like will still benefit from the 1:N relationship of the demodulation at the antenna end of the tower. In such instances, it is recognized that multiple cables would still be needed up the tower to the antenna, but the existence of HPAs at the masthead would be eliminated by the inventive demodulation apparatus and method.
- [0053] Overall, the present invention provides communications systems such as, but not limited to, CDMA cellular systems with significant capacity improvements. These improvements are a direct result of base station sector trunking efficiencies beyond those obtainable from individual per sector power amplifiers. This results from the fact that, in CDMA cellular systems, mobile traffic distribution is normally unequally distributed across sectors. Consequently, one sector usually reaches its maximum power (i.e., maximum traffic) capability before the others and additional users are then blocked from access to the sector. However, the present invention allows RF power from the other under-utilized sectors to be re-routed to the heavily loaded sector. Accordingly, significantly greater offered traffic could be accommodated before blocking occurred which effectively increases the base station's maximum traffic capacity.
- [0054] This invention enables all of the RF power from all of the sectors to be available at any sector to match any (arbitrary) sector traffic load combination. This process is automatic and consequently improves the base station's traffic capacity despite unbalanced sector loads. Further, reducing the number and size of antenna tower RF cables helps system operators control their capital expenditures by reducing the tower's reinforcing requirements. Also, in cases where the antenna tower is shared or leased by the system operators, the rental expenses often increase as cables are added. Importantly, in such situations system operators may be prevented from expanding the

number of antenna tower cables (needed to support the traffic load increases). This of course, directly impacts future revenue improvements at those sites.

[0055] The problems noted above are exacerbated by the recent introduction of smart antenna systems that generally require significantly more RF cables than conventional systems especially when the HPAs are not mounted at the tower top. The present invention overcomes this by allowing base station RF interfaces to remain relatively simple (with only one or two transmitter and receiver ports per sector) and yet still be capable of interfacing and utilizing phased array systems having six, eight or more input and output ports.

[0056] It should be understood that the preferred embodiments mentioned here are merely illustrative of the present invention. Numerous variations in design and use of the present invention may be contemplated in view of the following claims without straying from the intended scope and field of the invention herein disclosed.